0.1 Introduction

Climate risk assessment is becoming central in contemporary activities related in any way to the environment and whose assets could be affected by climate change. In particular, climate change risk assessment is a topic more and more organizations are considering in their decisions.

A climate change risk assessment for a given system is the analysis of the impacts of and the responses to climate change regarding that system. Various guidelines are available for these kind of risk assessments (cfr. [?, ?, ?]) and authors of assessments (e.g. consulting firms) follow a common procedure. This procedure can be summarised in few steps:

1. Collect requirements, documentation and information in general from clients and users about the system which is the subject of the assessment.

2. Collect from the client data and information about climate, environment and exposed samples concerning the assessed system.

3. Determine hazards potentially affecting the exposed samples of the system and their exposure and vulnerability.

4. For each determinant, identify indicators suitable to describe the system.

5. Quantify indicators using collected data.

6. Unify previous information and climate projections to obtain the final risk, also projected into the future using specific climate change scenarios.

7. Propose mitigation and adaptation measures and responses based on the outcome of the risk assessment.

In general, slight variations of this procedure is adopted by authors and guidelines do not specify precisely the practical details of the assessment. In particular, there is no objective method to choose the climate indicators used in the assessment, but they are selected according to their effectiveness in scientific literature and in previous assessments, combined with the personal experience of the authors. The choice of the indicators is far from objective.

0.1.1 Structure of the document

The landview of terms and definitions used in climate change risk assessment is varied and this may cause confusion. For the sake of clarity, definitions are provided, along with the sources they are taken from. If no specification of the source is present, the definition is assumed to be taken from [?] or [?]. Terms which are present in both sources have equivalent definitions.

0.2 Data

Climate data show great complexity in structure and availability, for instance Essential Climate Variables (ECVs) can be represented as multidimensional objects. For these and other properties discussed in [?], climate data can be regarded as big data.

In this work a generic ECV V can be represented mathematically as a scalar function

$$V : S_{\text{lat}} \times S_{\text{lon}} \times S_{\text{time}} \to \mathbb{R} \tag{1}$$

where S_{lat}, S_{lon} and S_{time} are domains of latitude, longitude and time dimensions, respectively.[1] Every numerical value is equipped with proper units of measurement, to represent physical quantities correctly. As a consequence, the codomain in equation (1) is partially wrong: with an abuse of notation, it represents only the magnitude of the ECV and does not consider the unit of measurement. This is a small exception to simplify the notation and in the remainder of this document units of measurement are always addressed explicitly.

A more practical representation of V is a multidimensional array, where values in the domain are coordinates associated to each dimension and each entry of the array is the result of V evaluated on those coordinates. Figure 1 shows this representation visually. In the following, this representation is used to simplify the discussion and same ECV name is used both for the function and the multidimensional array.

Example

Near-Surface Air Temperature, symbol tas, is available for some coordinates and timestamps. It can be seen as the scalar function in equation (1), which associates each value in set $S_{\text{lat}} \times S_{\text{lon}} \times S_{\text{time}}$ to a value with unit K, or it can be represented as the multidimensional array in figure 1, where each entry is function (1) evaluated at the corresponding coordinates.

Normals used as reference depends only on spatial coordinates, hence they are functions

$$\bar{V} : S_{\text{lat}} \times S_{\text{lon}} \to \mathbb{R} \tag{2}$$

or equivalently, multidimensional arrays with spatial coordinates only. Normals are evaluated as explained in [?, 6] using an averaging period specific to each case study (cf. section ??).

[1] In contests related to Machine Learning these objects are called tensors. Since they may not satisfy the mathematical definition of a tensor, in particular the map may not be multilinear and the numerical sets may not be vector spaces, no reference to such objects is made in this work.

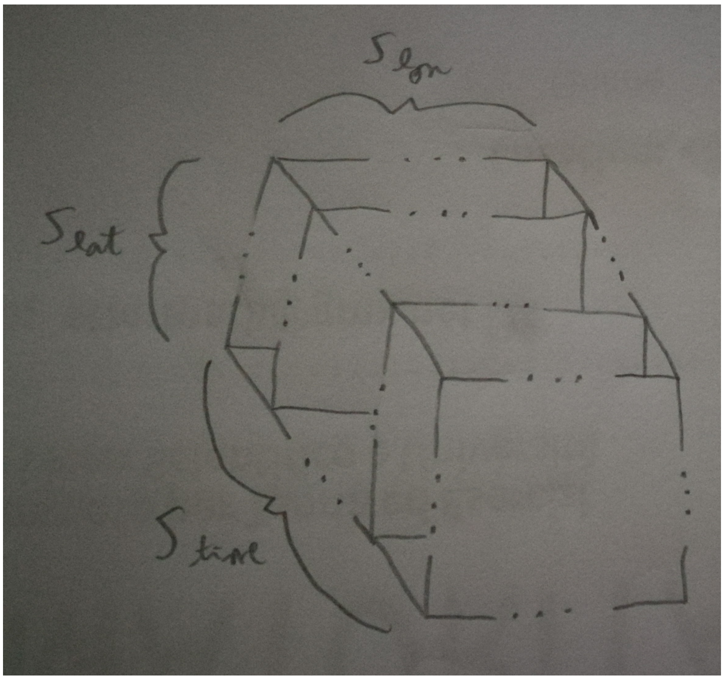

Figure 1: Representation of a generic ECV as multidimensional array.

Indicators are functions of ECVs and additional parameters may be needed in their definition. In general they are aggregated over the temporal dimension and in this work their evaluation is performed for each year, i.e. the indicator has yearly resolution or is evaluated with yearly frequency. Mathematically an indicator I can be defined as function

$$I : S_{\mathrm{lat}} \times S_{\mathrm{lon}} \times S_{\mathrm{y}} \times \prod_{p \in P_I} S_p \to \mathbb{R} \tag{3}$$

where S_{y} is a set of the years considered during the analysis, P_I is the set of parameters for that indicator and S_p is the set of values available for each parameter $p \in P_I$. As a symbolic shortcut, if $P_I = \emptyset$ then the indicator is defined only over $S_{\mathrm{lat}} \times S_{\mathrm{lon}} \times S_{\mathrm{y}}$. An indicator can be represented as a multidimensional array, similarly to ECVs.

Example

The indicator TX_{x} is evaluated for the period 1991-2020 with yearly frequency. This indicator is the monthly maximum value of daily maximum temperature,[?] hence:

- the ECV tasmax defined at daily frequency over the considered period is needed,

$$S_{\text{time}} = \left\{ t : \begin{array}{l} t \text{ day from 1st January 1991} \\ \text{to 31st December 2020} \end{array} \right\} \quad ;$$

- spatial dimensions are not specified, hence the evaluation is performed for each point of an arbitrary set $S_{\text{lat}} \times S_{\text{lon}}$;
- no additional parameters are required, $P_{\text{TX}_\text{x}} = \emptyset$;
- the outcome is a scalar value for each year in the period,

$$S_{\text{y}} = \{1991, 1992, \ldots, 2020\} \quad .$$

Definitions

hazard Here is used the IPCC's definition: "The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources", from [**?**, 2233]. Note that this concept focues on the negative impacts of the physical drivers, the term *Climatic impact-driver* is used for conditions with more general impacts (cfr. [**?**, 2224], [**?**, 10] and [**?**, 1871]). In this document the term Driver is used.. *see* driver

indicator "quantitative, qualitative or binary variable that can be measured or described, in response to a defined criterion", from [**?**] and also used in [**?**, **?**, **?**]. Some sources use the term *metric*.. 3

normal "period averages computed for a uniform and relatively long period comprising at least three consecutive ten-year periods", from [**?**, 2].. *see* period average, 2

period average "averages of climatological data computed for any period of at least ten years starting on 1 January of a year ending with the digit 1", from [**?**, 2].. *see* average

Acronyms

ECV Essential Climate Variable. 2, 3